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NATURAL AND INDUCED INFRARED MEASUREMENTS

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20 November 1974

Final Report for Period 1 October 1973 - 30 November 1974

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13. ABSTRACT

Infrared measurements of natural and induced sources were made and analyzed. Various spectral regions from 1 to 4.75 μm were measured with radiometers and a michelson interferometer. The sources included gas explosions, NH_4NO_3-kerosene explosions, rocket plumes, quiet night skies and night skies under auroral conditions. The data were reduced and partially analyzed. Throughout the measurements period the instruments were calibrated and improved to optimize the data obtained.

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INTRODUCTION

Under this contract Utah State University has planned and performed spectral measurements of natural and induced infrared background and target sources, maintained radiometer and interferometer instrumentation, and performed data reduction and analyses on measured data. Some of the data are being presented in official AFCRL reports. The major contractual efforts have been as follows:

1. Infrared measurements in the 1.56 to 4.67 μm region were made on explosives with interferometers and radiometers.

2. Infrared measurements in the 1.54 to 4.74 μm region were made of rocket plumes with radiometers and an interferometer.

3. Infrared atmospheric measurements in the 1 to 2 μm region were made from Poker Flat, Alaska, with the NIR radiometer system.

4. A rocking-filter technique was designed and tried on the near infrared (NIR) radiometer system to improve the instrument's spectral characteristics.

5. Periodic calibrations and maintenance were performed on the radiometer and interferometer systems.

6. Data reduction of measurements made from the aircraft with the Type III radiometer system was performed for the Hula-Hoop operation.

7. Scientific reports were written using the data measured under this contract.

MEASUREMENTS OF EXPLOSIVE SOURCES

Five methane-oxygen (CH_4-O_2) exploding balloons, fired in a Gas Explosive Simulation Test (GEST), and five NH_4NO_3 kerosene high explosive tests were measured from November 1973 through January 1974. The measurements were made with an infrared rapid scanning Michelson Interferometer (IRRS), a super-8 mm camera, and a fixed cold-filter radiometer. The instruments were all coaligned and hand tracked on the targets through a sighting telescope from a distance of 3425 feet from the target. Two additional signature radiometers were installed for the last methane-oxygen explosion and the NH_4NO_3 explosions.

The interferometer was used to obtain absolutely calibrated infrared spectra in the 2140 to 6400 cm^{-1} spectral region with 3.8 cm^{-1} spectral resolution. The cold-filter radiometer provided an absolute calibration check for the interferometer and provided a measurement of the absolute emission levels in a specified optical bandwidth. The signature radiometers have a response time of about 5 μsec; and therefore, provided good information during the ignition period in addition to absolute level information throughout each test. Since all of the instruments were coaligned with the camera, the movies from the camera film record confirm the tracking of the event.

Preliminary data reduction on the measurements has been performed jointly by AFCRL and Utah State University, and a preliminary report entitled "'GEST' Infrared Spectra at 1.56 to 4.67 Microns" has been generated by Brian P. Sandford, AFCRL/OPR and Ronald J. Huppi, Utah State University. An example of the spectra obtained is shown in Figure 1. This spectrum is one single .07-second scan of the many hundreds taken, and it is presented here as a representative sample of the data taken. This particular spectrum was taken at 1.59 seconds after ignition for the Double Exploding Balloon (DMB1) event. The large dip between 2200 and 2400 cm^{-1} arises from the atmospheric absorption by CO_2. The large dips between 3500 and 4000 cm^{-1} and between 5200 and 5500 cm^{-1} are caused by H_2O absorption. Primarily the emission part of the spectrum is interpreted to consist of the wings of the hot H_2O bands centered near 1600,

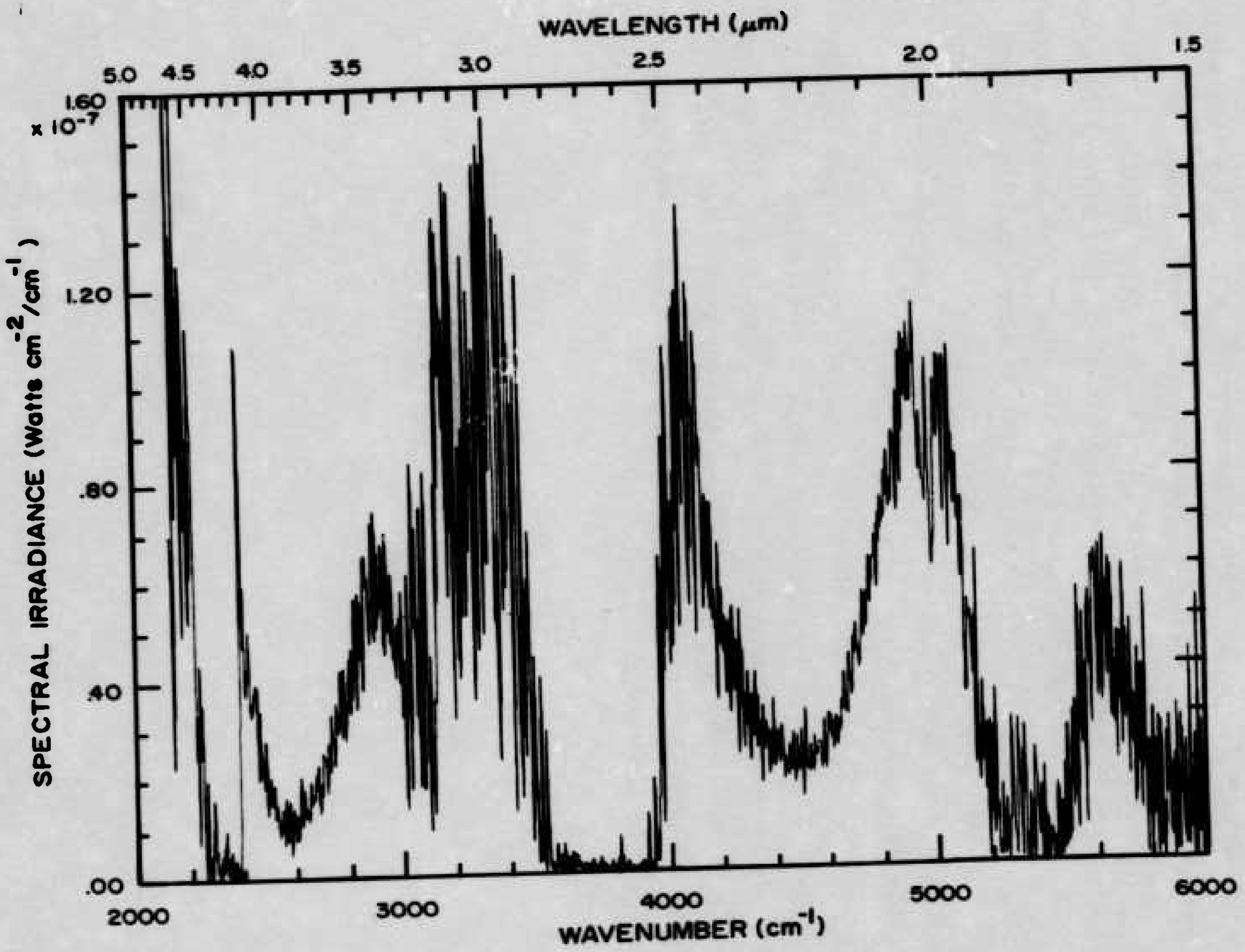

Figure 1. Typical spectrum of exploding balloon experiments.

3700 and 5300 cm^{-1}, hot CO_2 emission from the 2300 cm^{-1} band as it transmits through each side of the atmospheric CO_2 absorption band and hot CO in the 2200 cm^{-1} region. Spectra taken at other times for this event are similar; however, the relative intensities between the H_2O, CO_2 and CO bands do vary with time. In addition to the spectra, a good time history of the radiance centered at various wavelengths was obtained for fixed bandwidths. This was accomplished with spectral integrations and the radiometer measurements. Figure 2 shows a typical time history curve for the third exploding balloon (MB3) event. As shown, the time history of the radiance was measured over four orders of magnitude and the interferometer and radiometer data agree closely.

In general, the measurements were a complete success, and all equipment functioned excellently. Additional data reduction and analyses is underway for a detailed final report. The sponsorship provided by DNA was an important factor in the success of this program. The instrumentation was developed for a prior DNA project and was found very adaptable and suitable to this program.

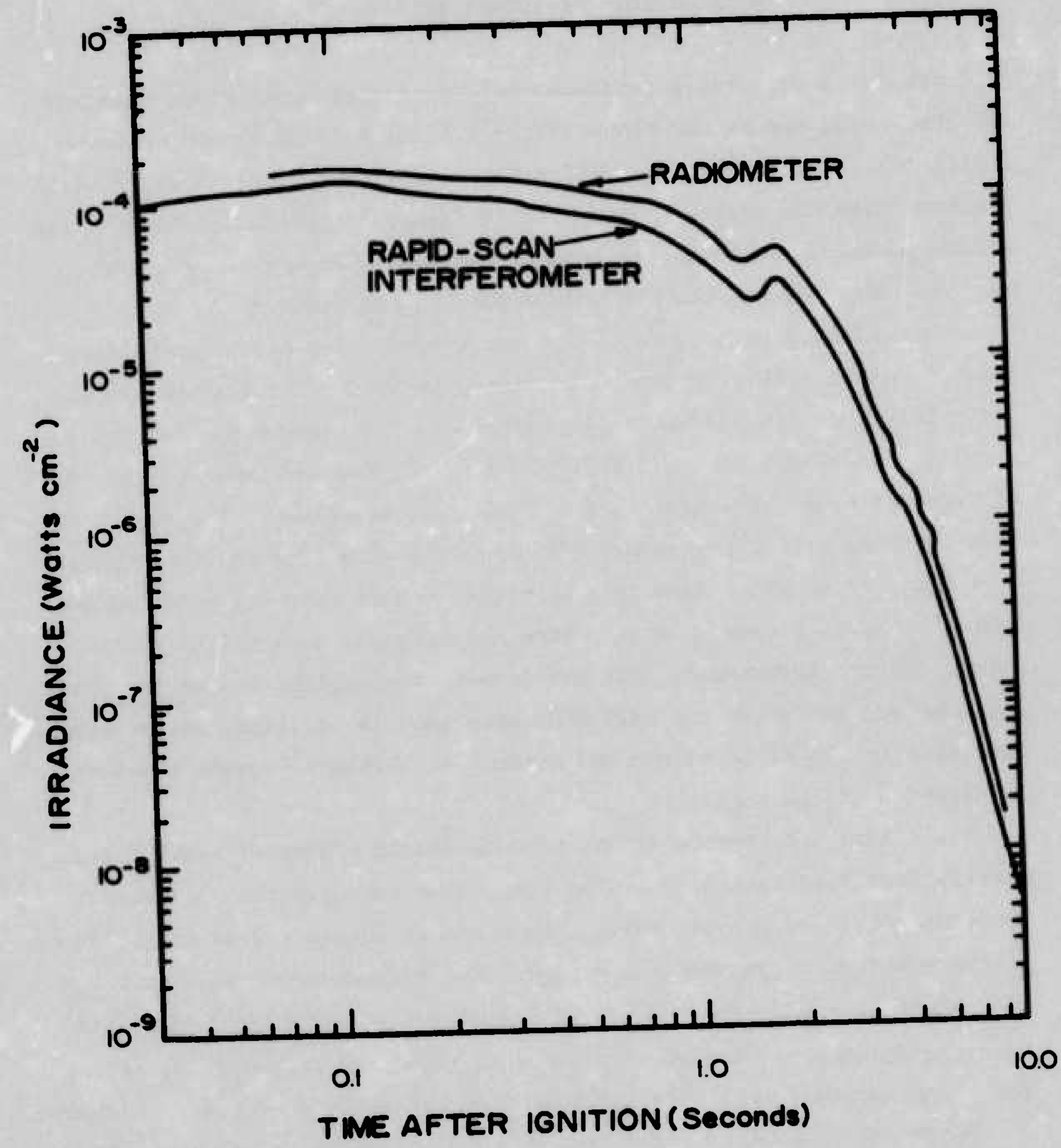

Figure 2. Typical fixed-band measurements at about 2.7 μm for the exploding balloon experiments (MB3 event).

MEASUREMENTS OF ROCKET PLUMES

Utah State University personnel set up instrumentation and obtained infrared signature measurements in the 1.67 to 4.67 μm region on seven static rocket firings in the GRIT SAND project. The contractual funding came from the Space and Missile Systems Organization (SAMSO) and the measurements were made as a cooperative AFCRL/SAMSO effort, with approval from DNA for the use of the DNA instrumentation.

The instrumentation consisted of an infrared rapid-scan Michelson interferometer (IRRS), three radiometers, an 8 mm color tracking camera and a telescope for aiming the instruments. The instrumentation was located in a van at a distance of 1410 feet from the test stand. The field of views of each instrument included the complete plume. The aspect angle from the nose of the engine was 67° 30'. The data from the instrumentation along with IRIG B time code information were recorded on a Sangamo Sabre IV magnetic tape recorder which allows great versatility in the data reduction techniques. All instruments were calibrated in the laboratory before and after the GRIT SAND program. In addition, calibrations were made in the field before and after each firing to ensure absolute calibration of the data.

The (IRRS) interferometer was used to obtain absolutely-calibrated spectra from 1.67 to 4.67 μm. The instrument measures the complete spectrum every .07 seconds which allows one to obtain a good time history of the spectrum throughout the events. The data were measured at a 1.9 cm^{-1} resolution unapodized which is equivalent to a 3.8 cm^{-1} resolution once apodization is performed in the data reduction process. Excellent data were obtained with this instrument on all seven of the events covered.

The three radiometers were used to take measurements at wavelength intervals within the 2.5 to 3 μm region. The instruments included two fast rise time (5 μsec) units to determine very detailed time history information and one cold filtered optically-chopped unit. These also provided an independent check on the interferometer data. Excellent results were also obtained with the radiometers on the seven events observed.

The interferometer data have been reduced by AFCRL; the radiometer data have been reduced by Utah State University. The data are being published in two official AFCRL classified reports by Brian P. Sandford, AFCRL/OPR and Ronald J. Huppi, Utah State University/Electro-Dynamic Laboratories. The titles of these reports are the following: "Infrared Signatures of GRIT SAND Motors NP003, 004, 007 and 008" and "Infrared Signatures of GRIT SAND Motors NP002, 005 and 006". Draft versions of these reports have been forwarded to MIA for inclusion in a comprehensive data report for project GRIT SAND. The data are basically similar to the spectral and radiometric data discussed in the previous section of this report. However, there were a few additional features which occurred in the spectrum. A typical example of one of these is shown in Figure 2a. The figure is a detailed portion of the measured spectrum showing HCl emission from the plume for one of the firings. Since the data are being formally published they will not be discussed further in this report.

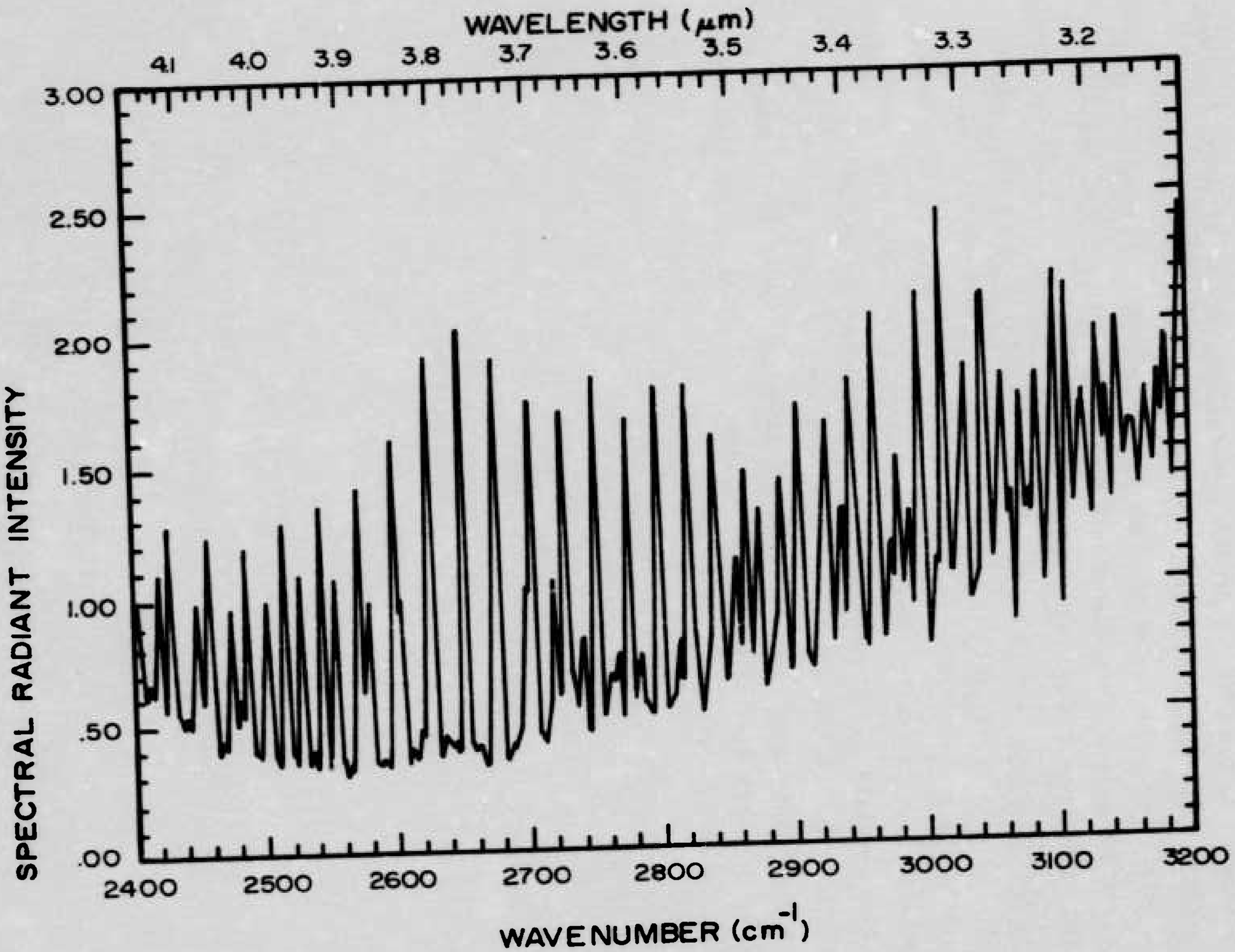

Figure 2A. Detailed HCL spectrum measured during the GRIT SAND program.

NIR RADIOMETER MEASUREMENTS

The aircraft NIR radiometer system was operated from the ground at Poker Flat, Alaska, at various times during January, February, March and April of 1974. The purposes of the measurements were threefold. First, they provided information for planning future aircraft measurement programs during a period of time when the aircraft was unavailable. Secondly, they provided ground based data for correlation with previous aircraft flights. Finally the measurements were used to support the ICECAP rocket instrumentation program.

During the measurement program the radiometers were operated at four different wavelengths with fixed spectral bandwidths. Figure 3 shows the relative spectral response of the instrument for these four wavelengths. The spectral response regions were selected to measure the $O_2(^1\Delta)$ 0-0 band at 1.27 μm, the Meinel N_2^+ lines in the 1.53-μm region, and various regions of the first overtone ($\Delta v = 2$) OH sequence. An explanation of the expected emissions in the various spectral response regions is given in Table 1.

TABLE 1

SPECTRAL EMISSIONS WITHIN THE SPECTRAL RESPONSE REGIONS OF THE NIR RADIOMETERS

Response Region Center Wavelength (μm)	Desired Emission Measurement	Other Emissions or Contaminations
1.5737	($\Delta v = 2$) OH 2-0 to 5-3 Bands	Meinel system of $N_2^+(A^2\Pi_u \rightarrow X^2\Sigma_g^+)$, The first positive bands of $N_2(B^3\Pi_g \rightarrow A^3\Sigma_u^+)$, $O_2(^1\Delta)$ 0-1 band at 1.58 μm
1.7003	($\Delta v = 2$) OH 5-3 Band	Contaminations are minimal.
1.53	Meinel N_2^+	($\Delta v = 2$) OH 3-1 Band
1.272	$O_2(^1\Delta)$ 0-0	Possible OH contaminations.

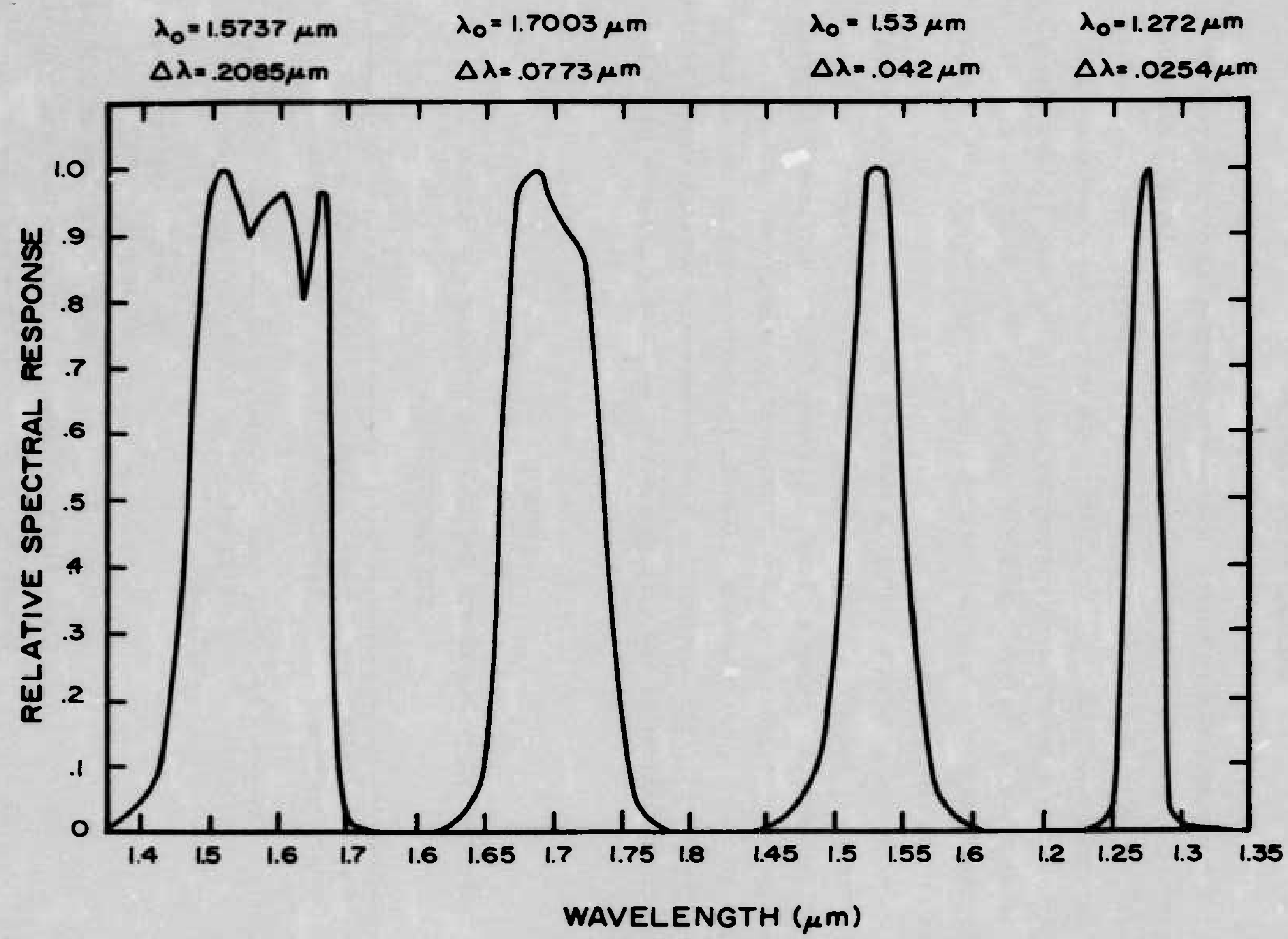

Figure 3. Relative spectral responses of NIR radiometer channels.

The data measured in this program have been reduced to graphs giving absolute calibrated levels as a function of time and should be useful for planning future aircraft measurements. Some of the data will be presented in a series of AFCRL reports for Contract F19628-72-C-0255 which provided the major share of the financial support for the measurements. A sample of the data during an auroral build-up and IR instrumented rocket launch is given in Figures 4, 5, 6 and 7 for the four wavelength regions. As shown in the figures, there are fluctuations in the emission intensities at all of the wavelengths. It is worth noting the rapid increase shown in Figures 4 and 5 for the 1.573 and 1.53 μm data at 0737 Universal Time. This increase corresponds in time with a bright visible aurora entering the field of view of the instruments. It is believed that this increase is caused by the N_2^+ Meinel lines. This interpretation is somewhat confirmed since the magnitude of the increase for the 1.7003 μm data, which is free of Meinel lines, does not show the same increase. At about 0739 UT the measured intensity of all the data increases. This increase was caused by emissions from the rocket plume fired at this time and should not be confused with atmospheric emissions. Another noteworthy observation in the 1.5737, 1.53 and 1.7003 μm data is the broad increase in intensity occurring between about 0730 to 0825. This increase is presently interpreted to be an increase in the OH levels possibly related to aurora. The phenomena discussed above seem to occur in most of the data collected in the program. In addition one should note that the fluctuations of the 1.27-μm $O_2(^1\Delta)$ intensities do not appear to correlate directly with either of these phenomena, and as one might expect the variations that do occur appear to have a much longer time constant.

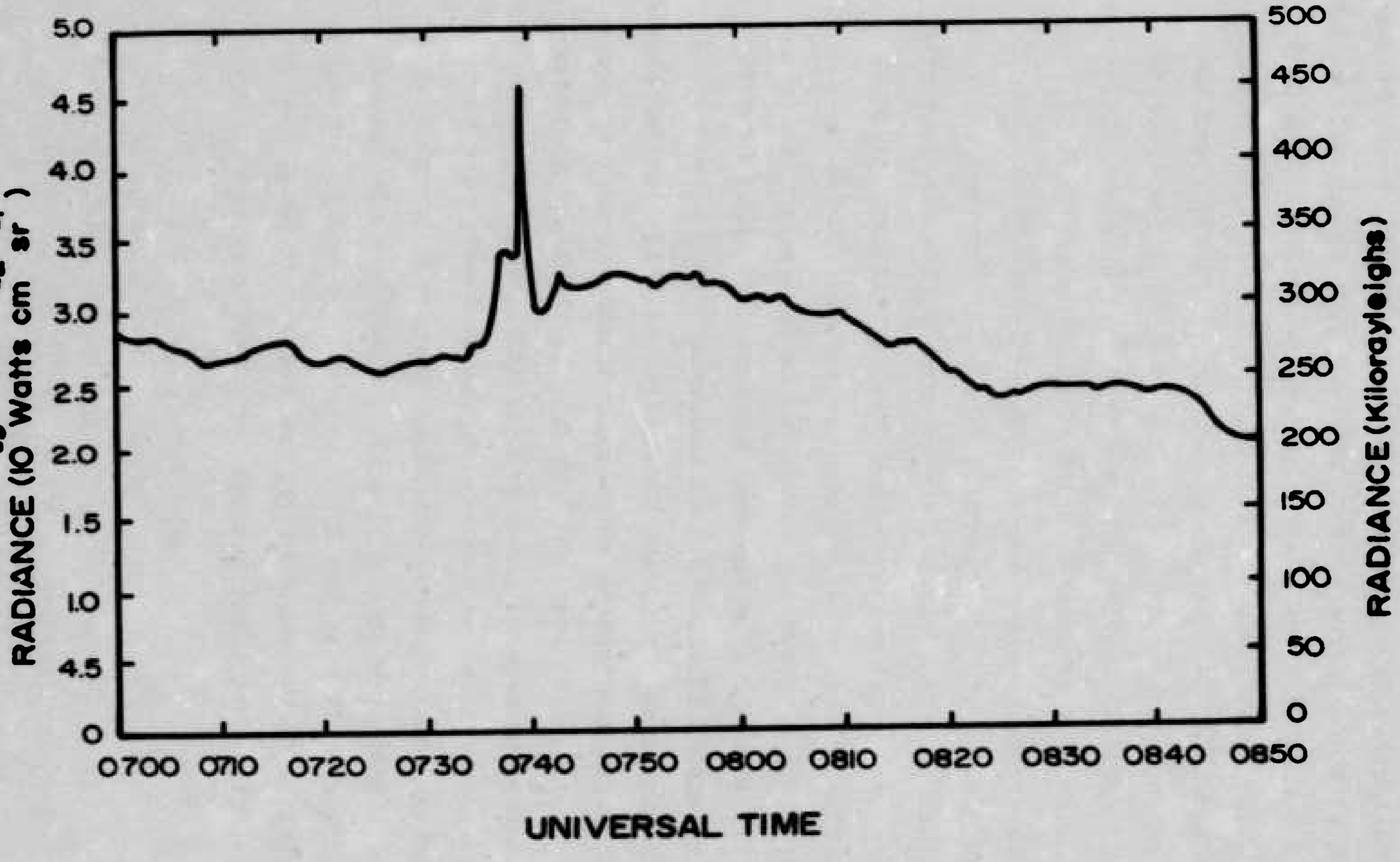

Figure 4. Radiometer measurement made at Poker Flat, Alaska, with λ_0 = 1.5737 μm, Δλ = 0.2085 μm and FOV = 10° on February 25, 1974 UT.

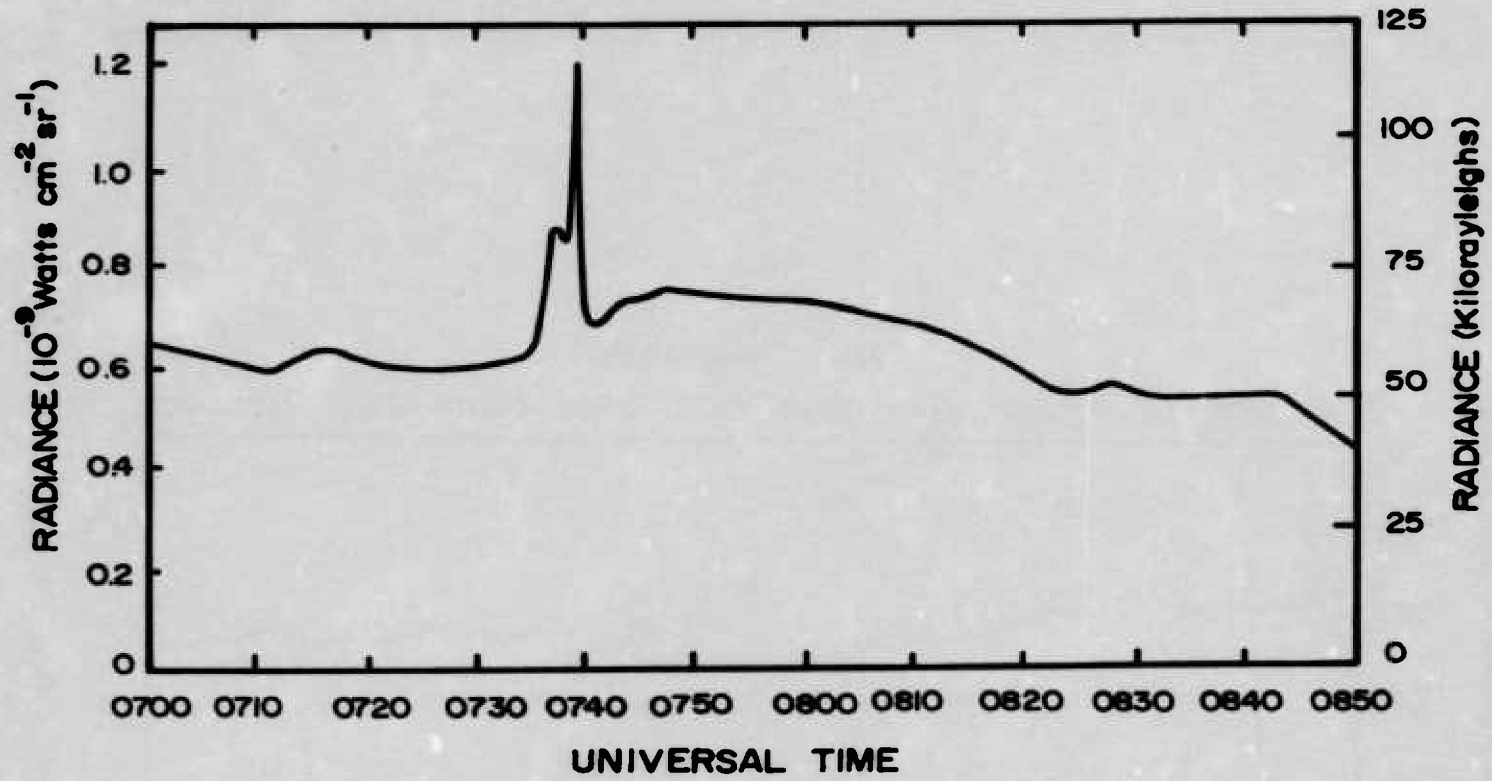

Figure 5. Radiometer measurement made at Poker Flat, Alaska, with λ_0 = 1.53 μm, $\Delta\lambda$ = 0.042 μm and FOV = 10° on February 25, 1974 UT.

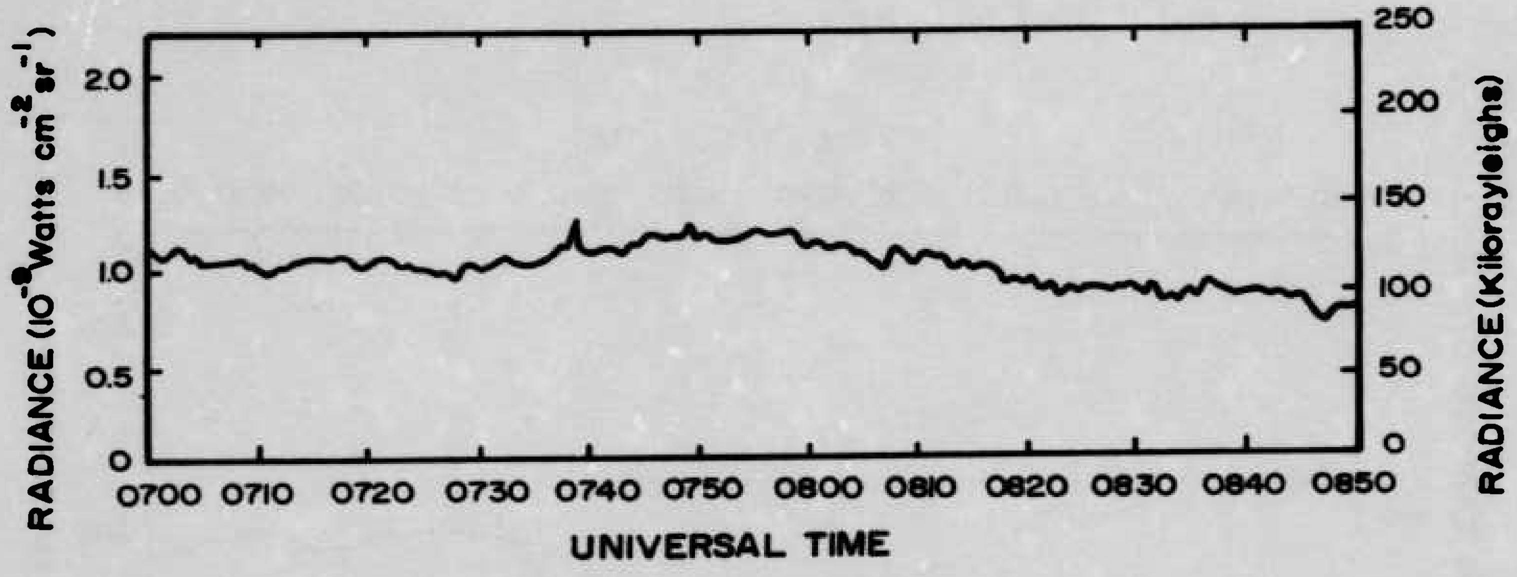

Figure 6. Radiometer measurement made at Poker Flat, alaska, with λ_0 1.7003 μm, $\Delta\lambda$ = 0.0773 μm and FOV = 1.8° on February 25, 1974 UT.

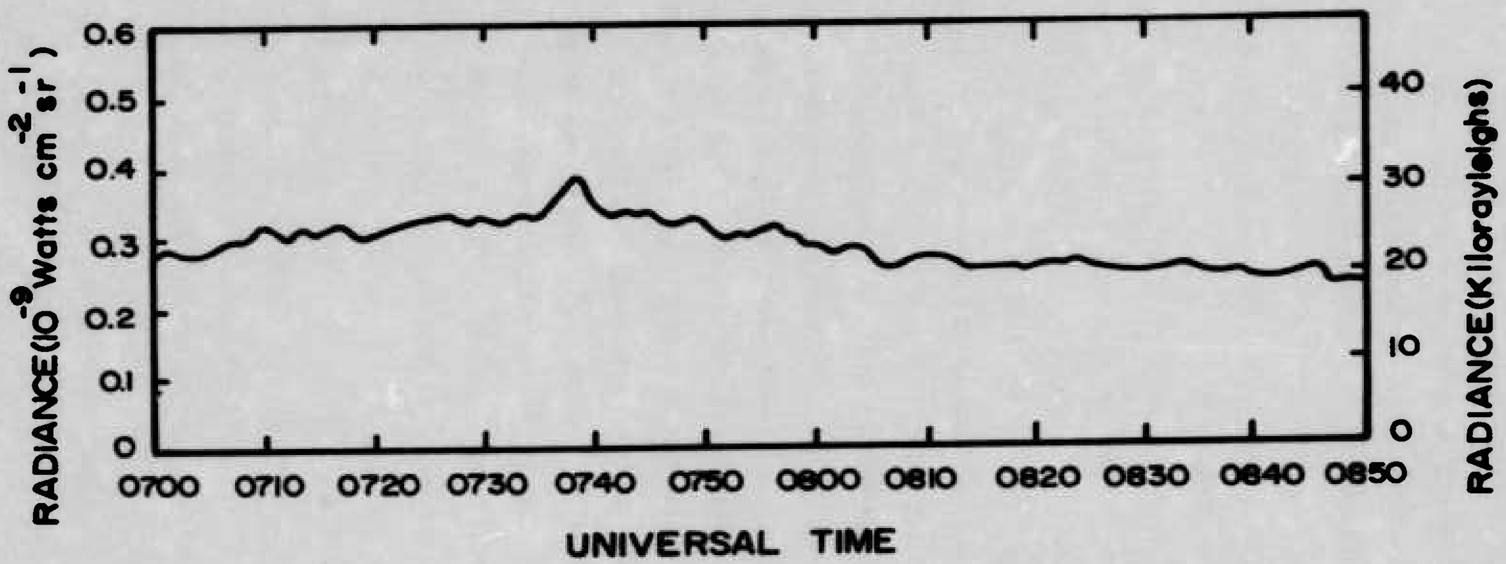

Figure 7. Radiometer measurement made at Poker Flat, Alaska, with λ_0 = 1.272 μm, $\Delta\lambda$ = 0.0254 μm and FOV = 10° on February 25, 1974 UT.

NIR RADIOMETER IMPROVEMENTS

The usefulness of the NIR radiometer system can be increased by modifying it to spectrally scan limited spectral regions. An experimental and theoretical investigation to determine the feasibility of using rocking filter techniques to accomplish this was performed. The practical limitations and usefulness of this technique for use in measurements of the OH ($\Delta v = 2$) region were considered.

Specifically, a study was made to determine if the Q line of the (5-3) transition of OH ($\Delta v = 2$) can be distinguished from the adjoining spectral features. As shown in a spectrum measured with the USU/AFCRL field-widened interferometer, Figure 8, this line occurs at about 5990 cm^{-1} or 1.669 μm. Since the center wavelength of an optical interference filter changes with incident angle, one can scan this region with a radiometer by gradually tilting a properly selected interference filter. Since the center wavelength of the filter decreases as the incident angle increases, it is necessary to select a filter centered at a slightly longer wavelength than 1.669 μm. The characteristics of the selected filter for zero degree angle of incidence are shown in Figure 9. When tilted to an angle of about 50°, the center wavelength shifts from 1.696 to 1.628 μm. The filter has a bandwidth of about .0144 μm which is good enough to distinguish the Q line of the (5-3) transition from other lines, since the nearest bright lines occur at 1.65 μm (6060 cm^{-1}) and 1.69 μm (5920 cm^{-1}).

An actual test measurement on the night sky was performed using the filter mounted in an automatic continuously rocking mechanism. The unit was designed to fit on the input optics of the NIR radiometers. Figure 10 shows the relative uncalibrated output as the scan was made. The measurement is preliminary and more tests are necessary, but initial indications show that the technique is useful for scanning lines in a limited spectral region.

The use of this technique has several advantages over fixed filter techniques. First, it does give spectral information with about .75% resolution (50 cm^{-1}) over a limited wavelength region. Secondly, measurements can be made further into twilight conditions, because the

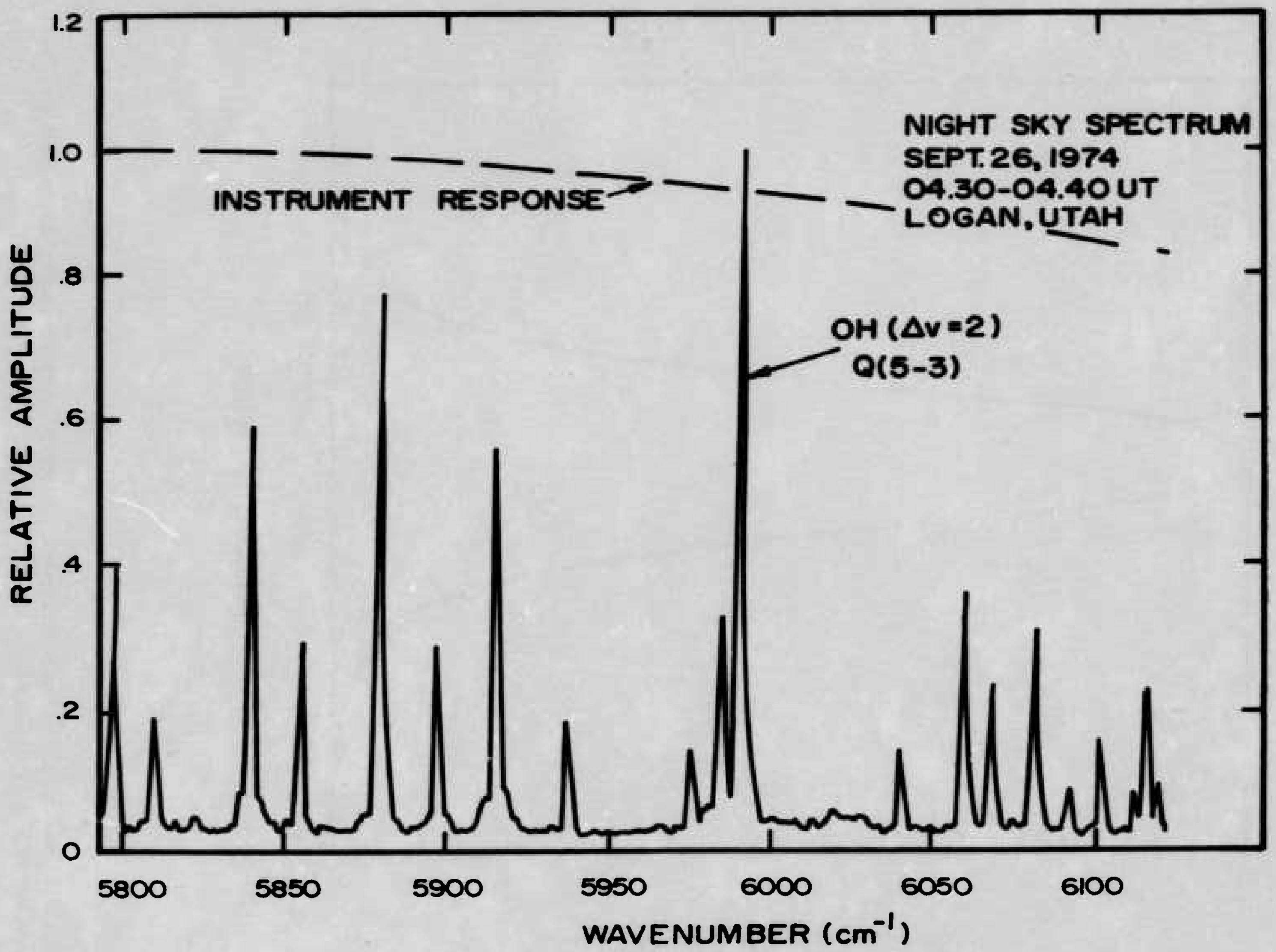

Figure 8. Typical night sky hydroxyl spectrum of a portion of the OH($\Delta \nu$ = 2).

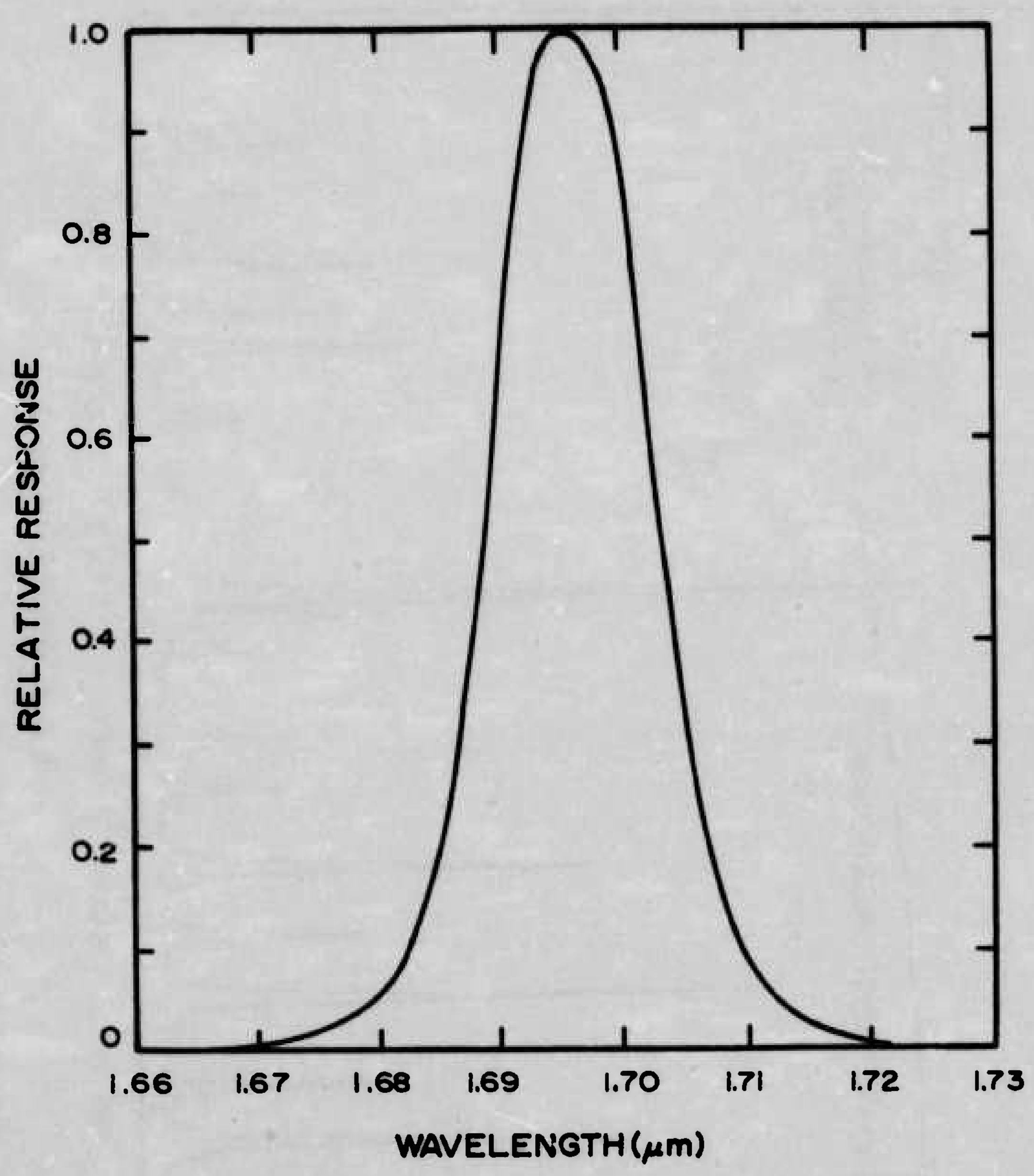

Figure 9. Relative filter response at zero degree angle of incidence for the scanning radiometer.

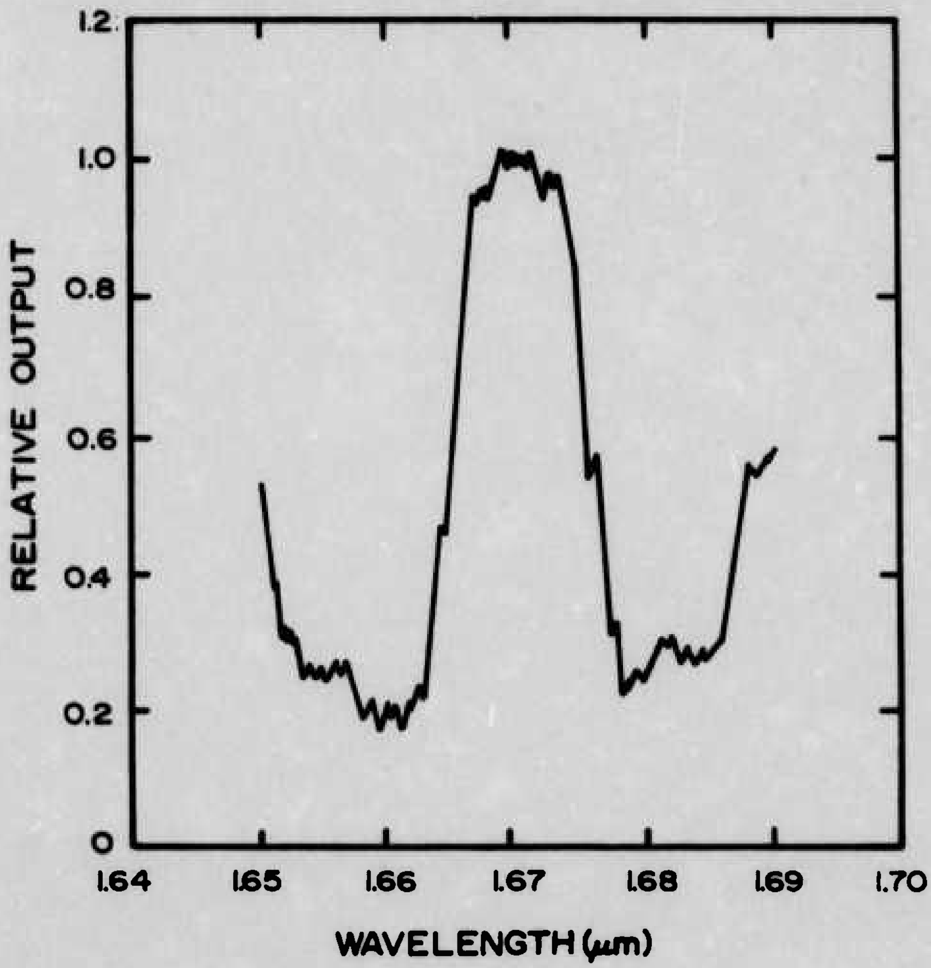

Figure 10. Typical relative output of the radiometer obtained by rocking the optical filter.

method distinguishes between line emissions and scattered continuum. Finally, the instrument can be used in a non-scanning fixed filter mode with the capability of adjusting the center wavelength. This is accomplished by stopping the scanning filter in various angular positions.

MAINTENANCE AND CALIBRATIONS OF INSTRUMENTATION

Throughout the contract the NIR radiometer system has been periodically maintained and calibrated. All parts were inspected monthly and calibrations were performed as needed. The system has operated very reliably over the past year, however a few parts such as power supplies and chopper motors have needed repair or replacement. The calibrations of the instruments have essentially remained constant. Calibrations made in December of 1973 agreed within 5% of the calibrations which were made in September of 1974. This indicates that the relative and absolute intensity numbers of the data taken with the radiometers should be very reliable.

Calibration and maintenance has also been performed periodically on the rapid-scan interferometer. The maintenance has involved electronic adjustments and periodic evacuation of the detector dewar. Calibrations have been performed on the instrument in the field and in the laboratory. Two calibration studies have been performed to determine if variations in instrument response occur with time. The first study involved checking the response periodically for several hours after cool down of the detector. The second study involved checking the response from time to time over a several month period. In both cases the response variations were small as shown in Figures 11 and 12. Figure 11 compares the relative response of the instrument for two calibrations performed about 10 months apart, and Figure 12 shows the calibrated response at two times about two hours apart after detector cool down.

These calibration studies were made possible through the use of the AFCRL/OPR fast Fourier transform data reduction system. Their assistance and direction were greatly appreciated.

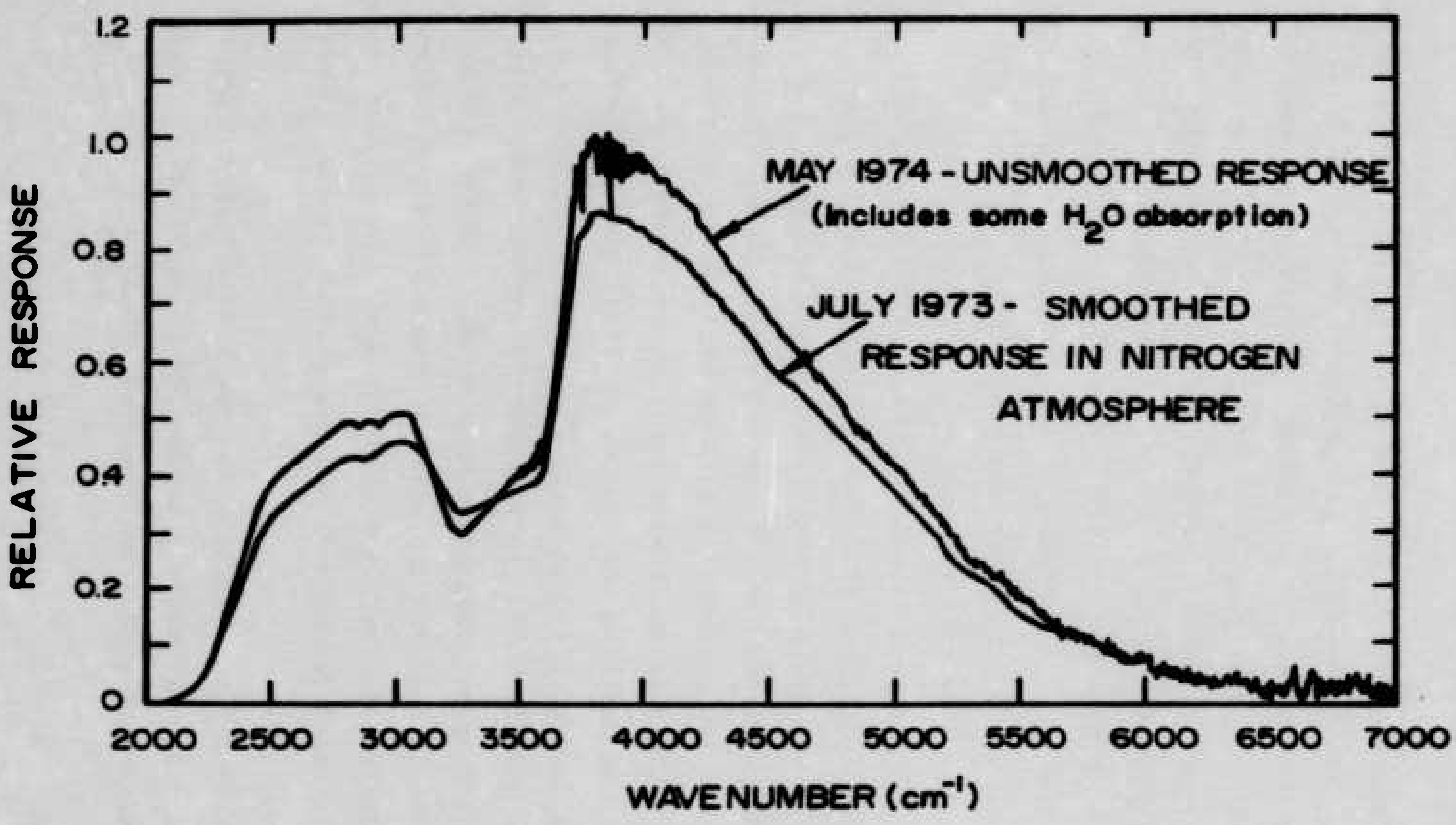

Figure 11. Relative spectral response of the rapid-scan interferometer measured about 10 months apart.

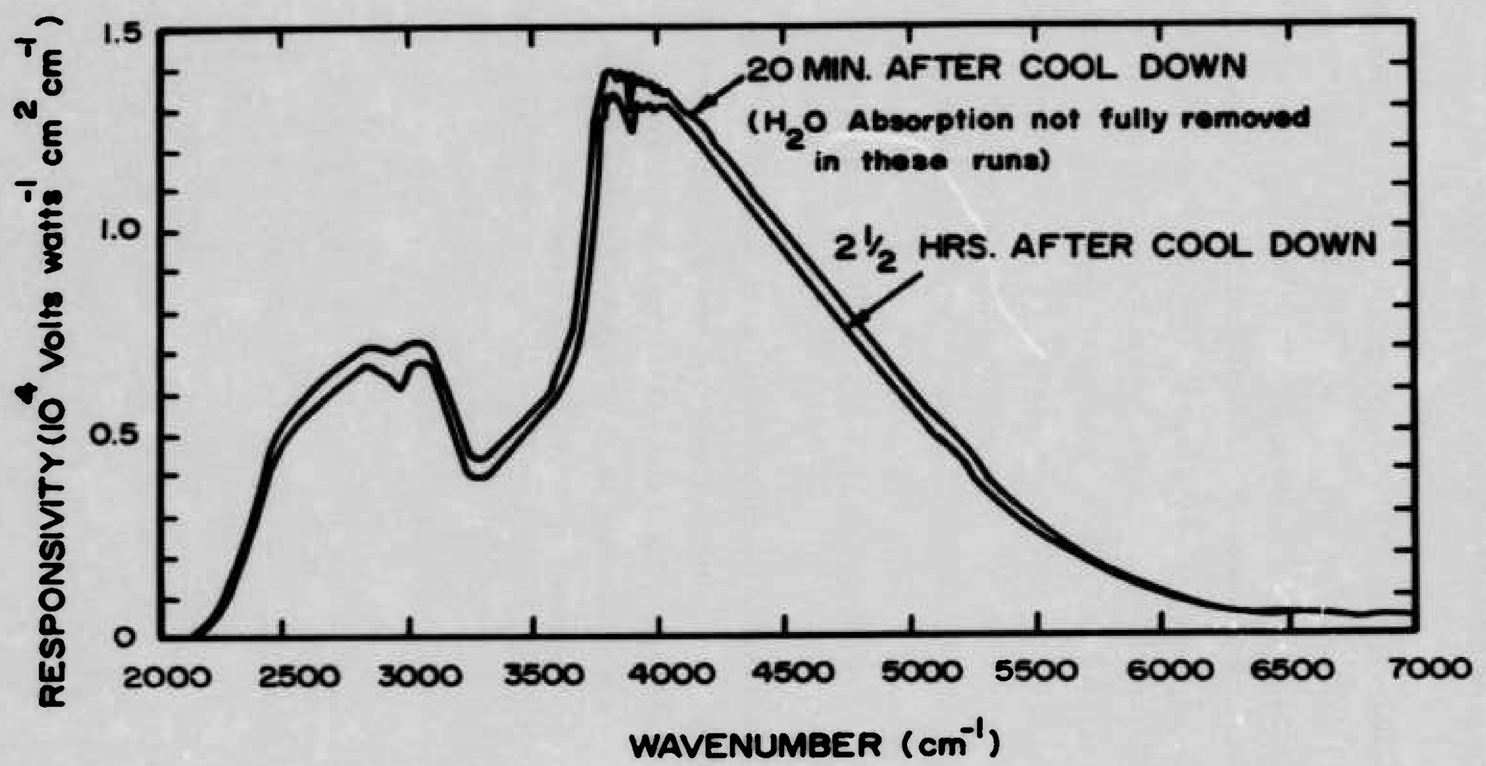

Figure 12. Absolute spectral response of the rapid-scan interferometer at two times after the detector was cooled.

DATA REDUCTION OF TYPE III RADIOMETER MEASUREMENTS

During the field operation in 1973, three radiometers were operated behind the Type III cold chopper system in the side mount position of the AFCRL aircraft S/N 53120. The radiometers consisted of two single-channel and one double-channel system. In addition, a single-channel cold, filtered radiometer was also operated independently giving a total of 5 channels of radiometric data. The radiometer spectral responses were defined by selected optical interference filters in the 1 to 15 μm region. Data reduction work on the measurements taken with these instruments was performed during this contract period. The method of reduction involved converting the data from analog to digital form on a USU PDP-8 microcomputer system. Once in digital form, the data could be put into an AFCRL program to obtain absolutely-calibrated irradiances and radiant intensities.

Present results show that the reduced radiometer data discussed above compare excellently with other radiometer and interferometer data taken during the field program. The data reduction needs further work and analysis, and it is not presented in this report because it has been and will be further presented in formal AFCRL reports.

RELATED REPORTS

The measured data and data reduction performed under this contract led or contributed to several reports. Many of the reports are in the process of being published as official AFCRL reports. Some of the reports are in the preliminary form but will be officially released shortly. The following is a detailed list of the publications:

Sandford, B.P., and R.J. Huppi, "Infrared signatures of GRIT SAND Motor NP003, 004, 007 and 008", Air Force Cambridge Research Laboratories, Hanscom AFB, Massachusetts, 1974.

Sandford, B.P. and R.J. Huppi, "Infrared signatures of GRIT SAND Motors NP002, 005, and 006," Air Force Cambridge Research Laboratories, Hanscom AFB, Massachusetts, 1974.

Huppi, R.J., and B.P. Sandford, "'GEST' infrared spectra at 1.56 to 4.67 Microns," Preliminary Report, Air Force Cambridge Research Laboratories, Hanscom AFB, Massachusetts, 1974.

"Ground Support Data Report In Support of Black Brant 18.219-1 Flight 25 February 1974 ICECAP 74A, Aeronomy Observatory," Utah State University, Logan, Utah, 1974.

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